GRAVITY SURVEY OF NEW BRUNSWICK

Mineral Resources Division
Department of Natural Resources
New Brunswick

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ABSTRACT

Compilation of all available gravity data for the province of New Brunswick has been completed. Data have been published at the scale of 1:50,000 and comprise 156 N.T.S. sheets. Regional interpretations are completed in the form of Regional, Residual, and 2nd Derivative gravity maps at the scale of 1:250,000 and 1:500,000. In addition, two-dimensional models have been computed for several gravity anomalies in the Moncton Basin.

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INTRODUCTION

As a result of the success of the 1971-1974 gravity project in delineating the Cassidy Lake, Plumweseep, and Millstream salt-potash deposits in southern New Brunswick, the Department of Natural Resources extended gravity mapping in 1977-1981 under a D.R.E.E. sponsored program. Additional coverage was needed to clearly define the extent of the existing deposits and also to evaluate the salt-potash potential in other regions of New Brunswick.

Under this second gravity project, all previous data gathered by the Department of Natural Resources, the Earth Physics Branch (E.M.R.), the University of New Brunswick and the private sector were combined with the more recent information collected by D.N.R. to make up a comprehensive network of 22,671 gravity stations. The combined data set has been compiled and published in a series of 1:50,000 maps covering all of New Brunswick and includes sheets for the Northumberland Strait, Bay of Fundy, and adjacent parts of Quebec and Nova Scotia.

Prior to the publication of the 1:50,000 Bouguer Anomaly gravity maps, regional maps at the 1:250,000 and 1:500,000 scales were produced utilizing larger spaced data published by the Earth Physics Branch. These larger scale Bouguer Anomaly maps were subsequently filtered for Regional Gravity, Residual Gravity and 2nd Derivative Gravity maps. The filtering parameters utilized in the preparation of these maps were derived from an evaluation of the waveform characteristics of five salt-potash gravity

anomalies in the Moncton Basin. These maps not only contribute to the better understanding of the salt-potash potential of the province but also provide valuable information for geothermal, uranium, coal, base metal, and petroleum exploration.

Modelling studies of known and probable salt masses were completed in areas with suitable gravity coverage. These areas include Dorchester, Cassidy Lake, Smithtown, Salina, Plumweseep, Anagance, Millstream, Penobsquis, Portage Vale, Five Points, and Point de Bute.

DATA ACQUISITION AND PRECISION

Instrumentation and the theory of the gravity method are described in Appendix I and Appendix II respectively.

Gravimetric Data

Base stations were established at major road intersections, on bridge foundations, Land Registration and Information Service monuments, and near prominent buildings. These base stations were then tied in to the Earth Physic Branch gravity control stations in the area. The loops were closed with a maximum error of ±0.10 milligals.

Traverses were then made from the base stations using a forward looping method. The time limit for most traverses was set at one hour. Again, the maximum closure error accepted was ±0.10 milligals.

Vertical Control

The elevation of each gravity station was determined by differential levelling from L.R.I.S. monuments. For the E.D.M. and Zeiss levels, the precision was ±.3 m. For the altimeters, the precision was determined at ±3 m.

Horizontal Control

Station positions were located on 1" = ¼ mile and 1:10,000 orthophoto base maps by chaining or with the use of a "topofil" unit. For road coverage, the plotting error of individual stations is estimated at ±15 m. For cross country traverses across uncut lines, plotting error is of the order of ±100 m.

THE NEW CANADIAN GRAVITY DATUM

As part of this project, all previous gravity data in the Province was meshed into the network to make up a comprehensive data base. Gravity survey work prior to 1974 was computed using the International Ellipsoid based on the Potsdam gravity value. This value was established as 978.2740 gals. However, later measurements at other stations tied into the Potsdam value indicated that the Potsdam value was about 11.8 mgal too high (Dobrin, 1952). In 1974, Canada abandoned the use of the Potsdam system which was based on theoretical gravity values computed on the 1930 International Ellipsoid. The gravity data is now based on the 1974 adjustment of the national gravity net which is consistent with the recently adopted 1971 International Gravity Standardization Net. The observed gravity is based on the 1971 International Gravity Standardization Net while the theoretical gravity is based on the 1967 Geodetic Reference System.

The formula for theoretical gravity in this new system:

$$G_T = 978031.85\ (1.0 + 0.005278895\ \sin^2\theta + 0.000023462\ \sin^4\theta)$$

Data calculated under the old system are converted to the new system using the formula:

$$G_{NEW} = G_{OLD} - 0.95 + 13.6\ \sin^2\theta + 0.05\ \theta \text{ mgal}$$

where G_{NEW} = Bouguer anomaly value in the new system

G_{OLD} = Bouguer anomaly value in the Potsdam system

The Earth Physics Branch (E.M.R.) who proposed the equation in 1974 claim that over small areas less than a few hundred square

miles, the equation is accurate to within a few tenths of a milligal.

NEW BRUNSWICK GRAVITY NETWORK

This report documents 22671 gravity stations in New Brunswick and adjacent areas. For continuity of interpretation of New Brunswick geology across its boundaries, data has been recorded for the Bay of Fundy, Northumberland Strait, parts of the Gulf of St. Lawrence, Bay of Chaleur, and adjacent parts of Quebec, Prince Edward Island and Nova Scotia. At the time of writing of this report, data for the ajacent part of the State of Maine was not added. However, it is hoped that this will be completed soon. The network of points fall within latitudes $44^{\circ}30'$ and $48^{\circ}30'$ and longitudes $63^{\circ}30'$ and $69^{\circ}30'$. The distribution of 1:50,000 map sheets is shown in Plate No. 82-4 and Appendix III.

A breakdown of the network is as follows:

Earth Physics Branch (E.M.R.)	=	7537
N.B. Department of Natural Resources	=	14064
K.B.S. Burke (1970)	=	165
Nova Scotia Research Foundation (1975)	=	264
A. Spector (1976)	=	641
TOTAL		22671

In combining all available data it was found that numerous repetitions occurred because of duplication of readings by several mappers. This was especially true for areas in Southern New Brunswick. The first task therefore was to remove such data from the computer file. To delete these repetitious values, the following steps were taken. Where gravity stations were

recognized to contain the same latitude (±.01 min.), longitude (±.01 min.), and Bouguer anomaly (±.1 mgal), one station was retained and the others deleted from the file. Despite this screening, several other repetitions were identified. This second set showed similar latitudes and longitudes but showed different Bouguer anomaly values. Since it is impossible to verify which data is wrong, the repeating stations were retained in the file. However, the repeating station is flagged and identified on the print-out by the letter R (example Table 1).

The data have been plotted on 1:50,000 map sheets as shown in Figure 1. Identified in the legend of each sheet, is the total number of gravity stations available for the sheet. For several of the sheets in the southern part of the province, extremely high station density has made it impossible to computer plot every station at the 1:50,000 map scale. For such high density sheets, data has been screened to allow legible printing of some stations, without distorting the value of the information. This screening was accomplished in the following way. Where a gravity station was identified to fall within the printing range of another station already plotted on the map, it was bypassed. The bypass parameters are as follows:

Latitude	±.14 minute
Longitude	±.40 minute

(Examples shown in Figures 2 and 3).

The gravity stations plotted on the respective 1:50,000 sheets are flagged and identified in the printout accompanying

YR	ID	STATION	LATITUDE	LONGITUDE	ELEVATION (METRES)	ELEV CODE	WATER DEPTH	WATER CODE	ADJUSTED GRAVITY	BOUGUER GRAVITY
76	0	5370001	45 15.18	-63 40.76	90.34	2	0.0	1	980618.4	-5.8*
76	0	5370002	45 15.84	-63 45.19	92.57	2	0.0	1	980619.1	-5.6*
76	0	5370003	45 15.85	-63 55.73	48.49	2	0.0	1	980631.8	-1.6*
76	0	5370004	45 16.32	-63 31.78	111.83	2	0.0	1	980619.5	-2.2*
76	0	5370005	45 16.41	-63 51.35	57.00	6	0.0	1	980629.9	-2.7*
76	0	5370006	45 16.68	-63 35.88	147.22	6	0.0	1	980612.9	-2.4*
76	0	5370007	45 18.15	-63 42.53	11.40	2	0.0	1	980644.8	0.6*
76	0	5370008	45 18.67	-63 38.66	39.04	2	0.0	1	980641.0	1.5*
76	0	5370009	45 18.70	-63 34.70	44.65	2	0.0	1	980639.6	1.1*
76	0	5370010	45 18.73	-63 47.42	29.57	6	0.0	1	980640.4	-1.1*
76	0	5370011	45 21.42	-63 54.70	12.80	6	0.0	1	980640.4	-8.4*
76	0	5370012	45 23.28	-63 53.58	14.48	2	0.0	1	980653.0	1.7*
76	0	5370013	45 23.28	-63 53.58	14.48	2	0.0	1	980654.1	2.8R
76	0	5370014	45 23.74	-63 32.28	17.53	5	0.0	1	980645.3	-6.1*
76	0	5370015	45 23.77	-63 32.31	15.48	2	0.0	1	980646.1	-5.8
76	0	5370016	45 23.78	-63 39.45	20.15	2	0.0	1	980644.7	-6.3*
76	0	5370017	45 23.79	-63 56.92	10.00	1	0.0	1	980656.4	3.4*
76	0	5370018	45 23.83	-63 48.79	29.54	2	0.0	1	980646.9	-2.3*
76	0	5370019	45 23.90	-63 33.50	17.07	0	0.0	1	980644.9	-6.8*
76	0	5370020	45 24.36	-63 43.48	18.56	2	0.0	1	980645.9	-6.2*
76	0	5370021	45 25.00	-63 36.04	11.28	6	0.0	1	980651.6	-2.9*
76	0	5370022	45 25.80	-63 54.08	63.70	6	0.0	1	980646.6	1.2*
76	0	5370023	45 26.28	-63 46.41	36.88	6	0.0	1	980649.4	-2.0*
76	0	5370024	45 26.29	-63 50.41	85.65	6	0.0	1	980641.3	-0.6*
76	0	5370025	45 26.58	-63 31.76	43.89	6	0.0	1	980647.3	-3.2*
76	0	5370026	45 26.93	-63 38.57	122.83	6	0.0	1	980635.2	-0.3*
76	0	5370027	45 27.30	-63 58.16	231.65	6	0.0	1	980626.3	11.6*
76	0	5370028	45 27.88	-63 53.76	209.40	6	0.0	1	980628.2	8.3*
76	0	5370029	45 28.04	-63 44.57	142.04	6	0.0	1	980640.9	7.5*
76	0	5370030	45 28.13	-63 40.72	107.93	2	0.0	1	980648.4	8.1*
76	0	5370031	45 28.42	-63 36.13	92.35	2	0.0	1	980654.4	10.6*
76	0	5370032	45 29.04	-63 31.86	138.99	6	0.0	1	980652.3	16.8*
76	0	5370033	45 29.11	-63 49.26	269.75	6	0.0	1	980618.6	8.7*

TOTAL 33, PLOTTED 33, REPEATS* 1, E. P. B. 33, D. H. R. 0, BURKE 0, H. S. R. F. 0, SPECTOR 0

Table 1. Printout format of gravity data accompanying each 1:50,000 map sheet.

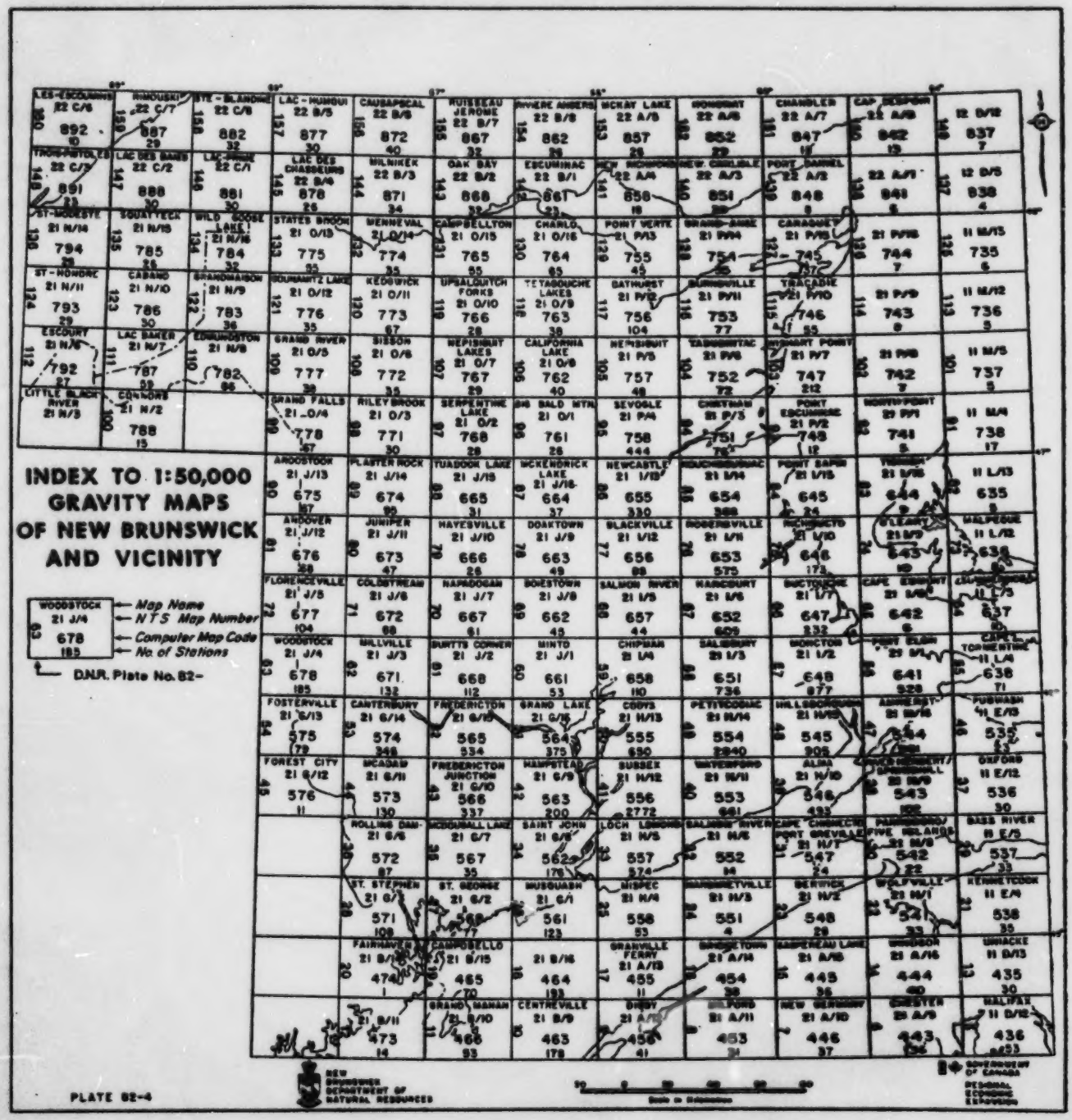

Figure 1. Index to 1:50,000 Gravity Maps of New Brunswick and Vicinity.

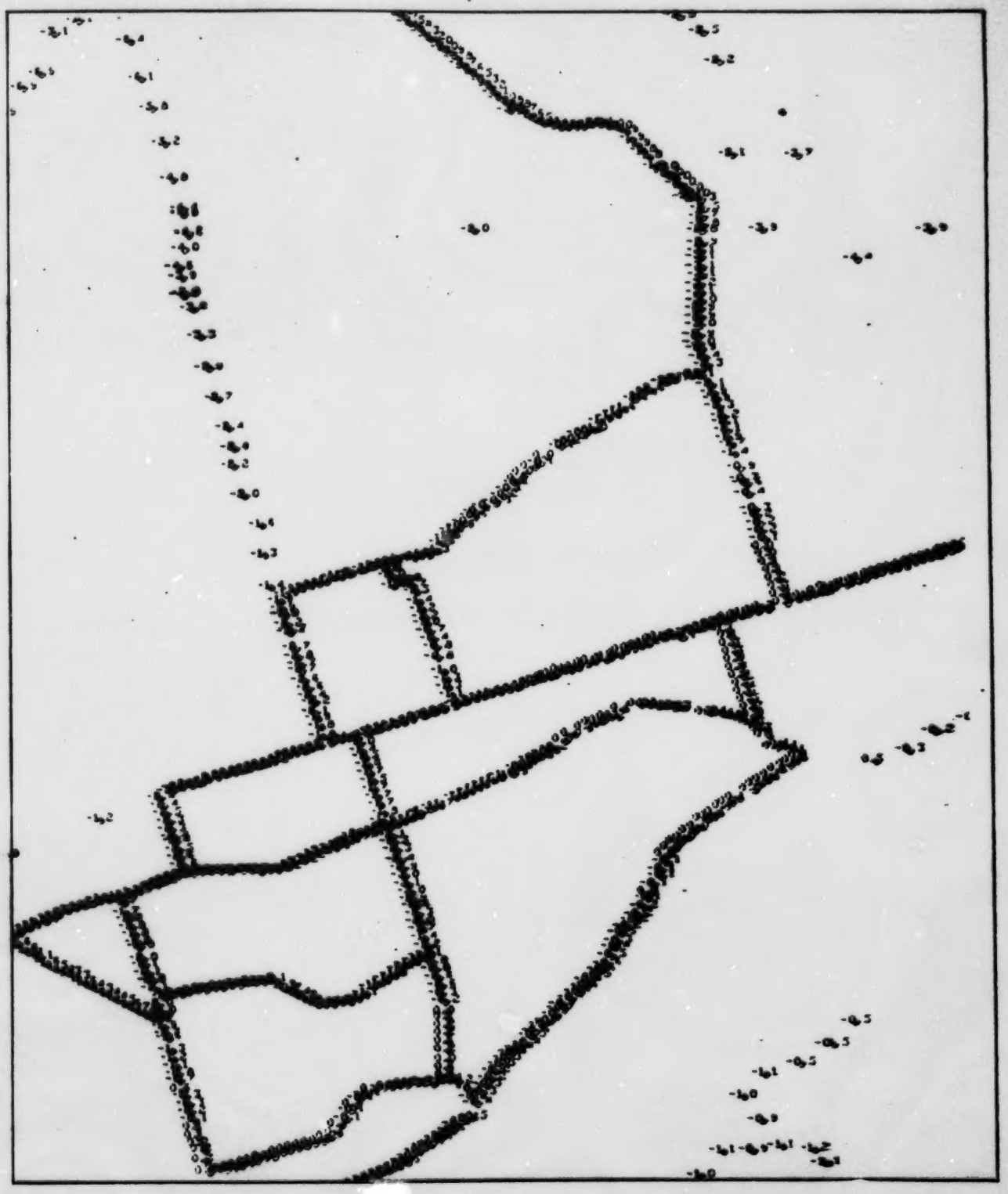

Figure 2. Clustering and overprinting of gravity data points due to high data density.

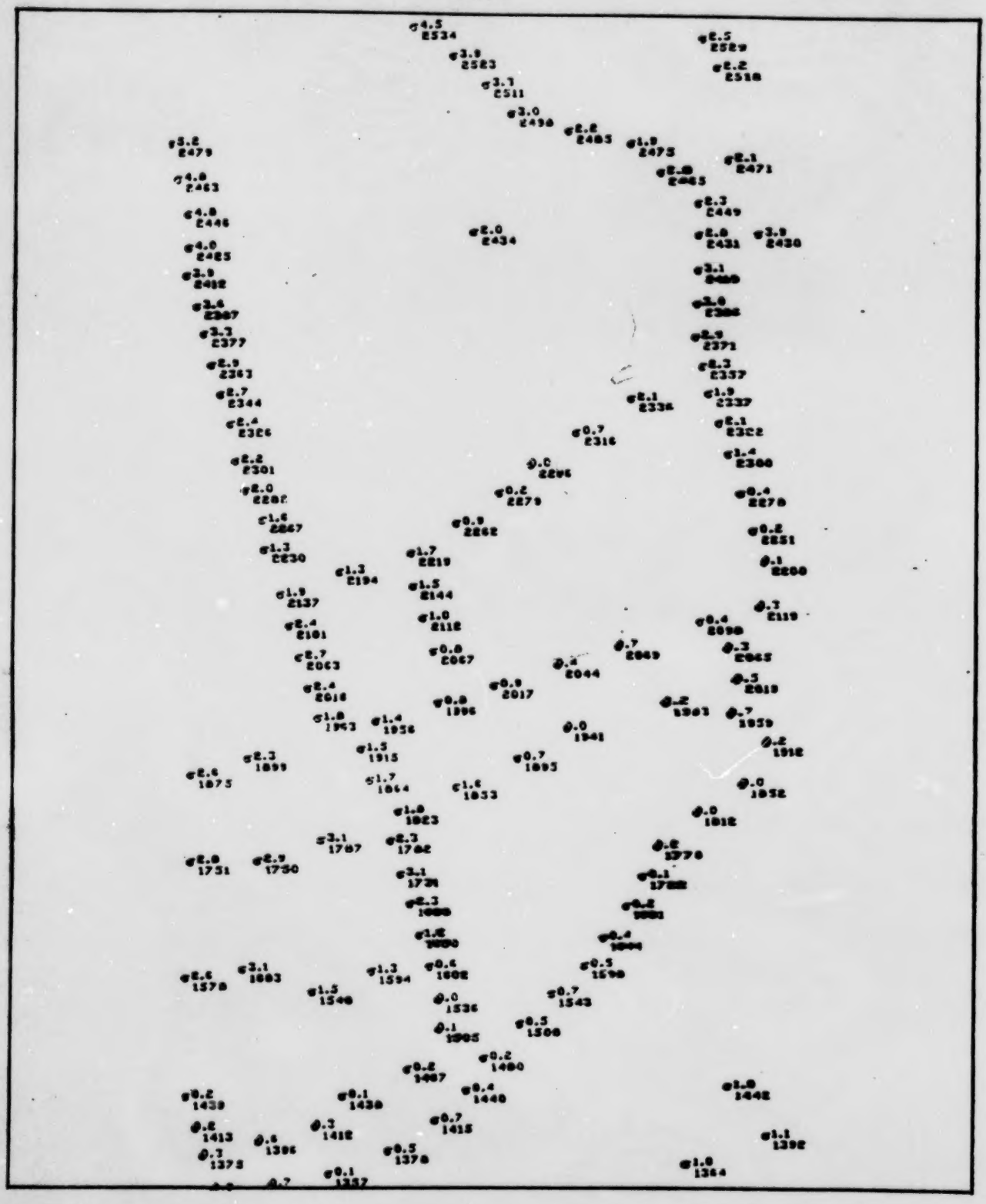

Figure 3. Screening of gravity points resulting in legible printing.

each map sheet by an asterisk (*). This option allows users to include the unplotted data at their own discretion.

Station Numbering Criteria

In order to allow for the automatic numbering of gravity stations on the respective 1:50,000 map sheets and on the computer file, the following system was implemented. The network of gravity stations were divided into data blocks of 1^{o} latitude and 1^{o} longitude respectively. Each 1^{o} lat. by 1^{o} long. block contains 8 full 1:50,000 sheets as shown in the example in Figure 4 . The bottom right hand corner (intersection of latitude 46^{o} and longitude 67^{o}) is used as the identifier of the block by utilizing the number 6 of lat. 46^{o} and the number 7 of longitude 67^{o}. The main block therefore is 67. The 8 compartments of block 67 (each component a 1:50,000 sheet) are numbered anti-clockwise from 1 to 8. The bottom right hand block is therefore 671 (Figure 4) and the other 7 blocks are (going anti-clockwise) 672 to 678. Having identified each 1:50,000 sheet thus, all gravity stations within the respective sheet are tacked on to the map sheet code. Example, Station No. 5 in the Millville 1:50,000 sheet will be in the printout as 6710005.

This numbering sequence was found neccessary to allow for fast compilation of data with the option of deleting or adding at any future time. Also, not all 1:50,000 sheets within the network have a name (e.g. Millville 21 J/3). There are several sheets in the off-shore area that are not labelled in the

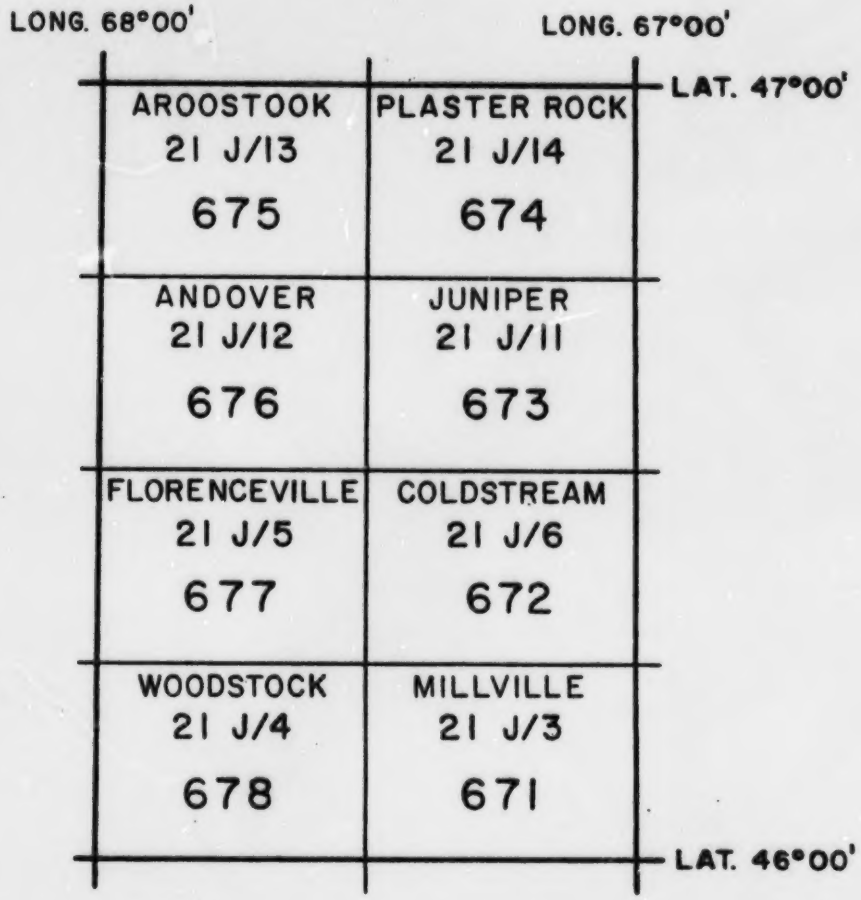

Figure 4. Illustration indicating map sheet code and station numbering sequence.

conventional way. The numbering system devised here therefore allows for the rapid identification of all points in the network. Stations falling on horizontal borders of the 1:50,000 sheets appear on the sheet above. Stations falling on vertical borders of the 1:50,000 sheets fall in the adjacent sheet to the left. Longitudes and latitudes are also maintained in the printouts and on the computer tapes that are part of the published package. The data stored on magnetic tape is formated as shown in Appendix IV.

REGIONAL 1:500,000 GRAVITY MAPS

Earlier in the project, it was considered necessary to compile regional gravity maps using the existing lower density data. These regional maps would provide a broader overview of the geology of the salt-potash deposits. Since the objective of the project was to determine the salt-potash potential of New Brunswick, it was clear that these regional maps should be designed to enhance the detection of such deposits. The filter parameters used in the generation of these maps therefore were selected after careful analysis of the residual characteristics of five known salt structures in southern New Brunswick (Chandra, et al., 1979).

Bouguer Anomaly Map (1:250,000 & 1:500,000)

The 1:500,000 Bouguer Anomaly Map (Plate No. 80-43) was compiled from Earth Physics Branch data at a density of approximately 36 km^2/point. Compilation of the regional Bouguer maps consisted of the manual contouring of 1:250,000 sheets of Bouguer anomaly data published by the Earth Physics Branch (EMR Open File Report No. 77-4).

Computer contouring of the data was impractical because the low density data did not yield reasonable anomaly shapes. This was due in great part to the unevenness of data distribution where areas of high data density were mixed with large poorly sampled blocks. The data set therefore was not in a matrix form to allow interpolation by conventional computer plotting packages.

Exceptional care was taken in hand contouring to maintain accurately certain important features of the original data. These features are resolution and shapes of individual anomalies, magnitudes and locations of peaks and troughs, and steepness of the field gradients. Interpolation was done by measuring separation distances between adjacent data points and inserting intermediate values assuming a continuous gravity field everywhere defined and linear. The result was 8 sheets at the 1:250,000 scale. These maps were then photographically reduced to make up the 1:500,000 regional Bouguer Anomaly Map of New Brunswick.

Filtered Maps

The compiled Bouguer Anomaly Map of New Brunswick, served as the data base for the determination of the Residual, 2nd Derivative and Regional gravity maps. In order to optimize anomaly separation of the Bouguer gravity data, it was necessary to investigate the change in residual anomaly with size of graticule required for filtering. To achieve this, gravity anomalies associated with five salt structures were selected for study. These were the Salt Springs, Plumweseep, Penobsquis, Millstream, and Weldon gravity anomalies.

The approximate centre of each of the above five anomalies was marked and a block of digitized data about each centre was obtained from the contoured Bouguer anomaly map. Using the 9-point method (Griffin, 1949), concentric squares of increasing side length were constructed about the centre point of each

investigated anomaly. The residual gravity for each increasing square was computed for each anomaly and plotted (Figures 5 and 6). From Figure 6 , the value of 5 km was selected for graticule size for the computation of the Residual, Regional and 2nd Derivative maps.

The Bouguer gravity map of New Brunswick was then digitized at a 2.5 km square matrix. On this grid of 2.5 km x 2.5 km, computations were done with a graticule size of 5 km and translation at 2.5 km (i.e. computations were done at every 2.5 km interval or every grid point in the array).

Of the Bouguer Anomaly, Regional, Residual, and 2nd Derivative regional maps, the Residual is the most useful for the interpretation of salt-potash potential in the Moncton and Central Carboniferous basins.

All the known and assumed salt masses in the Moncton Basin, fall within a well defined northeast striking Residual trend that runs from Smithtown to Weldon. This gravity trend then turns easterly to include the Dorchester salt deposit and the Cumberland Basin. Anomalies within this gravity trend are discussed individually in a later section.

In the Central Carboniferous Basin, similar gravity trends are noted striking in the same northeasterly direction. These gravity lows have been interpreted as graben structures in the pre-Carboniferous basement of the Central Carboniferous Basin. The most southerly of these grabens coincides with the Minto - Chipman and Beersville coal fields and hence suggest some association between deposition of coal and tectonics of the Central Basin.

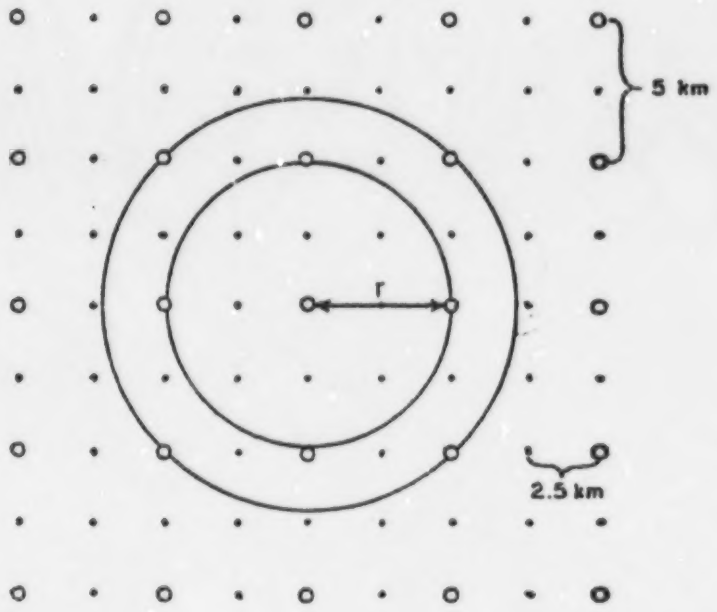

Figure 5 Optimum graticule size determined by the Griffin method and used for the calculation of residuals and derivatives.

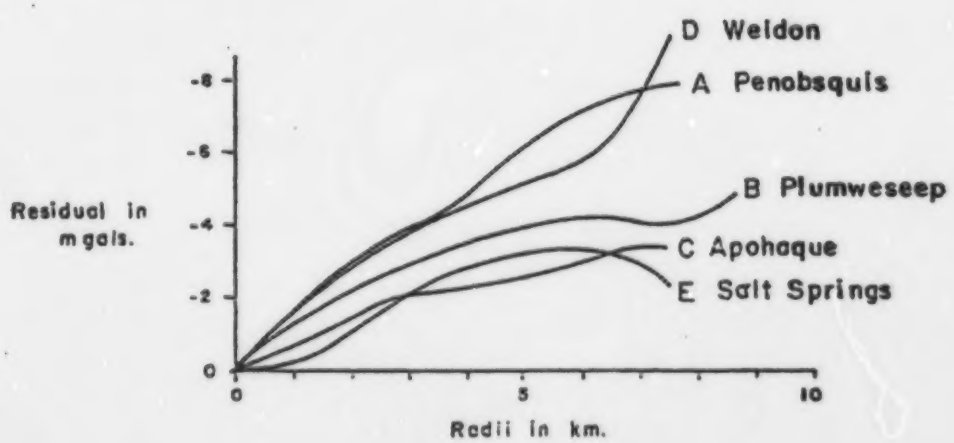

Figure 6 Graph of variation of residual gravity with inner radius of residual figure(circle).

Structural interpretation of the gravity data in the Central and Moncton Basins is shown in Plate No.82-178. The existence of grabens in the Central Basin will be of major significance in terms of evaporite potential. Drilling in the Central Basin (Ball, 1981) has failed in determining the existence of Windsor sediments. However, the shallow wells may have failed to reach these horizons, which if present, are preserved in the base of the grabens. The existence of the grabens also is of major importance in terms of uranium and base-metal potential.

The Regional Gravity map (Plate No. 80-41) indicates that the Central Basin is underlain by mostly shales and volcanic sediments. However, there are four distinct regions of large gravity lows interpreted as due to granites in the pre-Carboniferous basement. These are the Fredericton-North Forks, Clark's Corner, Richibucto, and Bois-Gagnon gravity lows (Plate No. 80-41).

Major northwesterly trending faults have also been delineated by the filtered gravity data and are identified by the abrupt changes and breaks in the "horst-graben" trends in the Residual and 2nd Derivative maps (Plates No. 80-42 and 80-44). However, these linears do not manifest themselves in the Pennsylvanian cover rocks and may be faults in the pre-Carboniferous basement.

Gravity data gathered since the compilation of these regional maps have added more detailed information especially in the Southern part of the province. It is hoped that at a future date, the regional gravity maps will be updated using the larger data base.

DENSITY MEASUREMENTS

Density information is required for the proper interpretation of gravity surveys. As part of this project, rock samples have been collected from many areas of southeastern New Brunswick and density measurements made with these samples. In addition, density measurements that were made as part of other gravity surveys in southern New Brunswick are summarized in this chapter. The density determinations were made by K.B.S. Burke (U.N.B.) under contract to the Department of Natural Resources. The laboratory procedure used in the determination of rock densities is described in Appendix V.

RESULTS OF DENSITY MEASUREMENTS

Tables 2 and 3 list the density values obtained as part of the present project for outcrop samples collected in the Dorchester and Smithtown-Salina areas. This information is supplemented by density measurements made on a few borehole core samples from the Cornhill, Sussex, Millstream, and Salt Springs areas reported in Table 4. Density values obtained as part of the previous salt exploration program are summarized in Tables 5 and 6. Finally, in Table 6, information on typical basement rocks is given by listing density values obtained for igneous and metamorphic rocks collected in the Caledonia Highlands (Gupta and Burke, 1977).

DISCUSSION OF RESULTS

If an allowance is made for the effects of weathering, 2.6 gms/cm^3 is a good representative density value for the sandstone and conglomerate rock units that overlie and enclose the known

evaporite deposits in southern New Brunswick. Evidence from the Salt Springs borehole (Table 5) suggests that if mudstones are present in the overlying sediments, then there is a significant increase from less than 2.5 gms/cm^3 near to the surface, to close to 2.7 gms/cm^3, at 1927 feet depth. Although a section containing a significant proportion of mudstone should be modelled with a variable density, a density value of 2.6 gms/cm^3 is probably an adequate representative value where the proportion of mudstone is minor (less than 20%).

The mean and standard deviation for the seven sample density values of halite reported in Tables 3 and 4 is 2.15 $\pm$ 0.03 gms/cm^3. This value has been rounded up to 2.2 gms/cm^3 for gravity modelling calculations. The three sylvinite sample values in Table 3 have a mean and standard deviation value of 2.05 $\pm$ 0.03 gms/cm^3 and suggests that there is a density contrast of -0.1 gms/cm^3 between sylvinite and halite. Because of the relative thinness of the sylvinite unit, with respect to halite, it is improbable that the effects of this density contrast can be detected by surface measurements of gravity.

A good representative density value for the gypsum samples is 2.3 gms/cm^3 and 2.9 gms/cm^3 represents the two anhydrite samples measured. A problem that occurs in using these values for modelling purposes is to decide the relative proportions of gypsum and anhydrite in a unit overlying a salt body. Because gypsum and anhydrite differ by 0.6 gms/cm^3 in density,

the actual density value of the overlying unit can vary quite widely. It is, therefore, recommended that the estimate of a representative density for such a unit be based on an empirically derived composition, such as was done in modelling the Dorchester anomaly.

The limestone, conglomerate, siltstone, and shales that underlie the evaporite deposits, can be represented with a density value of 2.7 gms/cm^3. Finally, as Table 7 shows, there is a range from 2.58 to 2.93 gms/cm^3 in typical basement rocks. It is, therefore, necessary to consider the contribution of changes in basement lithology to the gravity anomalies obtained in an area, and, if possible, to remove such effects by making a regional residual separation.

UNIT	DESCRIPTION	LONGITUDE	LATITUDE	NO. OF SAMPLES	MEAN DENSITIES AND STANDARD DEVIATIONS (gms/cc)			COMMENTS
					σ_g	σ_d	σ_s	
Windsor	Limestone	64°31.6'	46°56.0'	8	2.68±0.01	2.62±0.02	2.64±0.02	Upper Dorchester
Windsor	Gypsum	64°30'	45°45'	11		2.28±0.01		Cape Maringouin
Enrage	Conglomerate	64°30.7'	46°55.3'	5	2.68±0.02	2.54±0.03	2.59±0.03	Middleton
Enrage	Sandstone	64°31.1	46°54.4'	6	2.69±0.02	2.49±0.06	2.56±0.04	Dorchester

Table 2. Density values for samples collected in the Dorchester Area.

UNIT	DESCRIPTION	LONGITUDE	LATITUDE	NO. OF SAMPLES	MEAN DENSITIES AND STANDARD DEVIATIONS (gms/cc)			COMMENTS
					σ_g	σ_d	σ_s	
Albert	Sandstone	65°37'	45°36.5'	4	2.71±0.01	2.56±0.02	2.62±0.01	1 m* north of Southfield.
Albert	Shale	65°36'	45°38'	6	2.58±0.06	2.30±0.18	2.41±0.13	3/4 m east of Byrns Lake. Fissile and weathered.
Hammond River	Sandstone	65°28'	45°29.5'	4	2.59±0.01	2.45±0.02	2.50±0.01	Upham.
Hopewell	Sandstone	65°38.5'	45°33.1'	5	2.69±0.04	2.43±0.05	2.51±0.04	3/4 m north of Salt Springs.
Kennebecasis	Conglomerate	65°49'	45°29'	8	2.66±0.02	2.52±0.07	2.57±0.05	1¼ m north of Smithtown. Badly weathered.
Kennebecasis	Conglomerate	65°49'	45°27.5'	6	2.70±0.01	2.60±0.01	2.64±0.01	Smithtown Station.
Kennebecasis	Conglomerate	65°49'	45°26.5'	4	2.64±0.01	2.50±0.01	2.55±0.01	2 m S. W. of Smithtown. Highly weathered.
Kennebecasis	Conglomerate	65°42.5'	45°32'	5	2.63±0.04	2.50±0.02	2.54±0.02	1/3 m N. E. of Salina. Crumbly and weathered.
Kennebecasis	Conglomerate	65°44.4'	45°30.9'	4	2.68±0.01	2.60±0.01	2.63±0.01	2 m S.W. of Salina. Weathered.
Kennebecasis	Sandstone	65°45'	45°28'	5	2.57±0.03	2.46±0.03	2.50±0.03	½ m south of Salt Springs.
Kennebecasis	Sandstone	65°46.5'	45°29'	6	2.69±0.01	2.60±0.03	2.63±0.02	Robertson Station.
Kennebecasis	Sandstone	65°47.2'	45°30.1'	2	2.74	2.64	2.68	Robertson Road.
Kennebecasis	Sandstone	65°44.9'	45°29.5'	4	2.69±0.00	2.60±0.1	2.63±0.00	½ m north of Titusville.
Kennebecasis	Sandstone	65°48'	45°27.7'	5	2.60±0.01	2.50±0.01	2.54±0.01	3/4 m S.W. of Smithtown St.
Moncton	Conglomerate	65°37.5'	45°34.5'	3	2.72±0.02	2.66±0.02	2.68±0.02	1¼ m west of Clover Hill.
Moncton	Conglomerate	65°41'	45°34'	6	2.68±0.01	2.59±0.01	2.62±0.01	2 m N.W. of Salt Springs.
Moncton	Sandstone	65°40'	45°34'	3	2.68±0.03	2.64±0.03	2.66±0.03	2 m north of Salt Springs.

Table 3. Density values for samples collected in the Smithtown - Salina Area. Symbol m* = miles.

UNIT	DESCRIPTION	LONGITUDE	LATITUDE	NO. OF SAMPLES	MEAN DENSITIES AND STANDARD DEVIATIONS (gms/cc) σ_g	σ_d	σ_w	COMMENTS
Upham	Limestone	65°33'	45°32.5'	5	2.70±0.01	2.68±0.01	2.69±0.00	1 m west of Hillsdale.
Upham	Limestone	65°31.5'	45°33.3'	6	2.71±0.01	2.69±0.01	2.70±0.01	1½ m S.W. of Hammondvale.
Coldbrook	Tuff	45°25.8'	65°25.8'	7	2.72±0.01	2.71±0.02	2.71±0.01	½ m north of Brawly Lake.
Coldbrook	Ash	45°27'	65°45.5'	4	2.75±0.01	2.67±0.03	2.70±0.03	1 m N.E. of Third Lake.
Coldbrook	Ash	45°27'	65°43'	5	2.70±0.00	2.68±0.01	2.69±0.01	Between Barnsville Station and Barnsville.
Coldbrook	Tuff	45°31'	65°43'	3	2.68±0.01	2.65±0.00	2.66±0.00	1 m S.W. of Salina.
Precambrian intrusives	Granite	45°29'	65°47.5'	5	2.67±0.04	2.61±0.02	2.63±0.02	½ m N.E. of Smithtown.
Precambrian intrusives	Granite	45°34'	65°38'	6	2.63±0.00	2.57±0.01	2.59±0.01	1½ m N.E. of Salt Springs.
Precambrian intrusives	Granite	45°28.7'	65°47.6'	3	2.58±0.05	2.52±0.07	2.55±0.06	East of Smithtown Station.
Precambrian intrusives	Gabbro	45°28'	65°49.5'	5	2.83±0.01	2.79±0.01	2.80±0.01	1½ m S.W. of Smithtown Station.

Mean values of saturated densities classified according to rock type

Rock type	No. of samples	Mean density and standard deviation (gms/cc)	Unit
Conglomerate	28	2.59±0.05	Kennebecasis
Conglomerate	9	2.64±0.03	Moncton
Sandstone	22	2.59±0.06	Kennebecasis
Limestone	11	2.69±0.01	Upham
Granite	14	2.59±0.04	Precambrian

Table 3. (continued). Density values for samples collected in the Smithtown - Salina Area.

Sussex - Petitcodiac Sub-basin

Sample No.	Description	Density (gm/cc)
1	Mudstone J-4a	2.64
2	Sandstone G-4a	2.69
3	Claystone H-5	2.37
4	Solution Collapse Breccia D-3	2.41
5	Sylvinite P-4	2.03
6	Argillaceous Halite H-4a	2.12
7	Clear Halite N-3	2.12
8	Anhydrite (massive Penob #1)	2.89
9	Argillaceous Limestone Plum #1	2.67
10	Conglomerate E-8	2.49

Salt Springs Sub-basin

Sample No.	Description	Density (gm/cc)
1	Mudstone SS #1	2.48
2	Sandstone SS #1	2.13
3	Vuggy Siltstone SS #1	2.35
4	Sylvinite IMC 7	2.04
5	Clear Halite IMC 4	2.12
6	Anhydrite IMC 15	2.90
7	Red Halite IMC 12	2.12

Millstream Hole

Sample No.	Description	Density (gm/cc)
1	Conglomerate	2.55
2	Sandstone	2.57
3	Shale	2.55
4	Sandy Siltstone	2.61

Cornhill Hole

Sample No.	Description	Density (gm/cc)
1	m.g. Sandstone	2.52
2	f.g. Sandstone	2.58
3	Mudstone	2.70

Table 4. Density values for core samples from the Sussex, Salt Springs, Millstream, and Cornhill areas.

UNIT	DESCRIPTION	NO. OF SAMPLES	MEAN DENSITY AND STANDARD DEVIATION (gms/cc) $\bar{x}$ ± σ	COMMENTS
Hopewell	Sandstone	10	2.45±0.01	Samples badly weathered.
Windsor	Claystone	3	2.55±0.02	
Windsor	Gypsum	1	2.30	
Windsor	Sylvinite	1	2.08	
Windsor	Rock Salt	4	2.18±0.02	
Windsor	Limestone	2	2.72±0.02	
Moncton	Sandstone	2	2.74±0.02	

Table 5. Density values for samples collected in the Sussex Area. (from Chiasson 1973).

MILLSTREAM BOREHOLE
Longitude 65°38' Latitude 45°42'

Depth (ft.)	Lithology	Density value (gms/cc) σs	σd
47	Conglomerate	2.54	
507	Conglomerate	2.56	
1187	Sandstone	2.64	
1419	Conglomerate	2.63	
1887	Sandstone	2.43	
2130	Conglomerate	2.60	
2530	Conglomerate	2.62	
3001	Mudstone		2.68*
3081	Mudstone	2.62	

SALT SPRINGS BOREHOLE
Longitude 65°36' Latitude 45°34'

Depth (ft.)	Lithology	Density value (gms/cc) σs	σd
500	Mudstone	2.43	
700	Sandstone		2.47*
900	Sandstone		2.64*
1017	Mudstone	2.63	
1300	Sandstone		2.62*
1500	Mudstone	2.66	
1700	Sandstone		2.70*
1900	Mudstone	2.62	
1927	Mudstone	2.68	

*Determinations by Atlantic Analytical Services.

Table 6. Density values for core samples from Millstream and Salt Springs boreholes. (Waugh, 1975, written communication).

ROCK TYPE	NO. OF SAMPLES	MEAN DENSITIES AND STANDARD DEVIATIONS (gms/cm^3)		
		σg	σd	σs
Granite	36	2.64±0.04	2.58±0.05	2.60±0.04
Adamellite	7	2.67±0.03	2.65±0.03	2.66±0.03
Diorite	8	2.80±0.05	2.78±0.07	2.78±0.05
Gabbro	9	2.93±0.08	2.88±0.08	2.90±0.09
Rhyolite	29	2.62±0.04	2.56±0.05	2.58±0.05
Trachyte	16	2.65±0.02	2.64±0.03	2.65±0.03
Dacite	33	2.69±0.06	2.66±0.06	2.67±0.06
Andesite	64	2.81±0.07	2.79±0.07	2.80±0.07
Basalt	8		2.93±0.03	
Muscovite schist	16	2.68±0.07	2.66±0.06	2.68±0.05

Table 7. Density values for typical basement rock samples collected in the Caledonia Highlands (from Gupta and Burke, 1977).

MODELLING OF ANOMALIES

Because of their negative density contrasts with surrounding rocks, salt masses are usually characterized by distinctive gravity lows on the Bouguer anomaly map. However, on a typical Bouguer map, large-scale deep-seated structures may predominate to such an extent that it is very difficult to recognize smaller or shallower features which would indicate the presence of salt masses.

The anomalies discussed in the following sections are fairly obvious on the Bouguer maps, however, a high resolution residual gravity map of the Central and Moncton Basins may indicate others that are not presently noted. Data distribution (point density) in these basins is fair to poor despite the high number of gravity stations recorded in the area. Additional gravity coverage to give an approximate station density of 4 km^2 per point would add considerably more information than is presently available.

Several gravity anomalies have been identified in the Bouguer maps as being related to lower density masses within the sedimentary rocks of the Central and Moncton Basins. However, discussion here is restricted to those anomalies which are associated with Mississippian and younger rocks and which may be due to the presence of salt masses in the strata.

In order to evaluate the anomalies, profiles were constructed across their long axes. These profiles were extended well out from the anomaly to provide an estimate of the regional component of the observed gravity field. The regional field is determined

graphically by drawing a smooth line through the observed profile. The difference between this regional and the observed curve is termed the residual and is used in the interpretation. In the case of the Dorchester anomaly, the residual curve was obtained by a combination of the graphical and gridding techniques.

Modelling of each anomaly is performed by computing the theoretical gravity response of two dimensional bodies below the datum plane of the residual anomaly.

All available geological, geophysical and borehole information is considered in setting up a two dimensional stratigraphic section below the anomaly. Rock densities for the individual layers making up the section are obtained by density measurements of outcrop samples and from drill hole density logs if available. In the absence of such information, average density values are taken from published data.

The model is set up to represent a plausible geologic section for the area. These sections are identified in the respective 1:50,000 gravity map sheets. It must be stressed that several solutions are possible in providing a match to the residual curve. However, only the most plausible geologic section is modelled. Theoretical curves are computed for each unit comprising the section. The several curves are then summed and compared to the residual curve. Numberous adjustments are made to the units of the model until the computed curve matches the residual curve.

The computer program used in the modelling of anomalies in this project is after Talwani et al. (1959).

ANOMALY DESCRIPTIONS

Dorchester Anomaly

The Dorchester gravity anomaly is in the area of longitude 64°31'30" and latitude 45°54'30'. The anomaly is an elliptically shaped Bouguer low of -21 mgals which is superimposed on a dominant gravity field attributed to the Cumberland Basin (Plate No. 82-48).

In order to evaluate the significance of the gravity low, the regional component of the gravity field and the effects of a thick alluvial cover were removed from the Bouguer map. This is exemplified in a section (Profile 0 (W-E)) across the anomaly (Figure 7).

Profiles were made across the axes of the anomaly and stratigraphic cross sections were constructed using drill hole and geologic data. The stratigraphic section for Profile W-E is shown in Figure 8. The computed gravity model for the W-E section is shown in Figure 9.

The minimum depth to salt determined from modelling is in the range of 300-500 metres. The salt mass has been interpreted to be bounded by steeply-dipping faults both to the west and east. Detailed descriptions of the anomaly can be found in "Request for Tenders for the Right to Explore and Develop a Salt-Potash Prospect in the Dorchester Area, Westmorland County, New Brunswick" (D.N.R. 1981).

Smithtown, Salina, and Salt Springs Anomalies

The Smithtown, Salina, and Salt Springs anomalies are centred

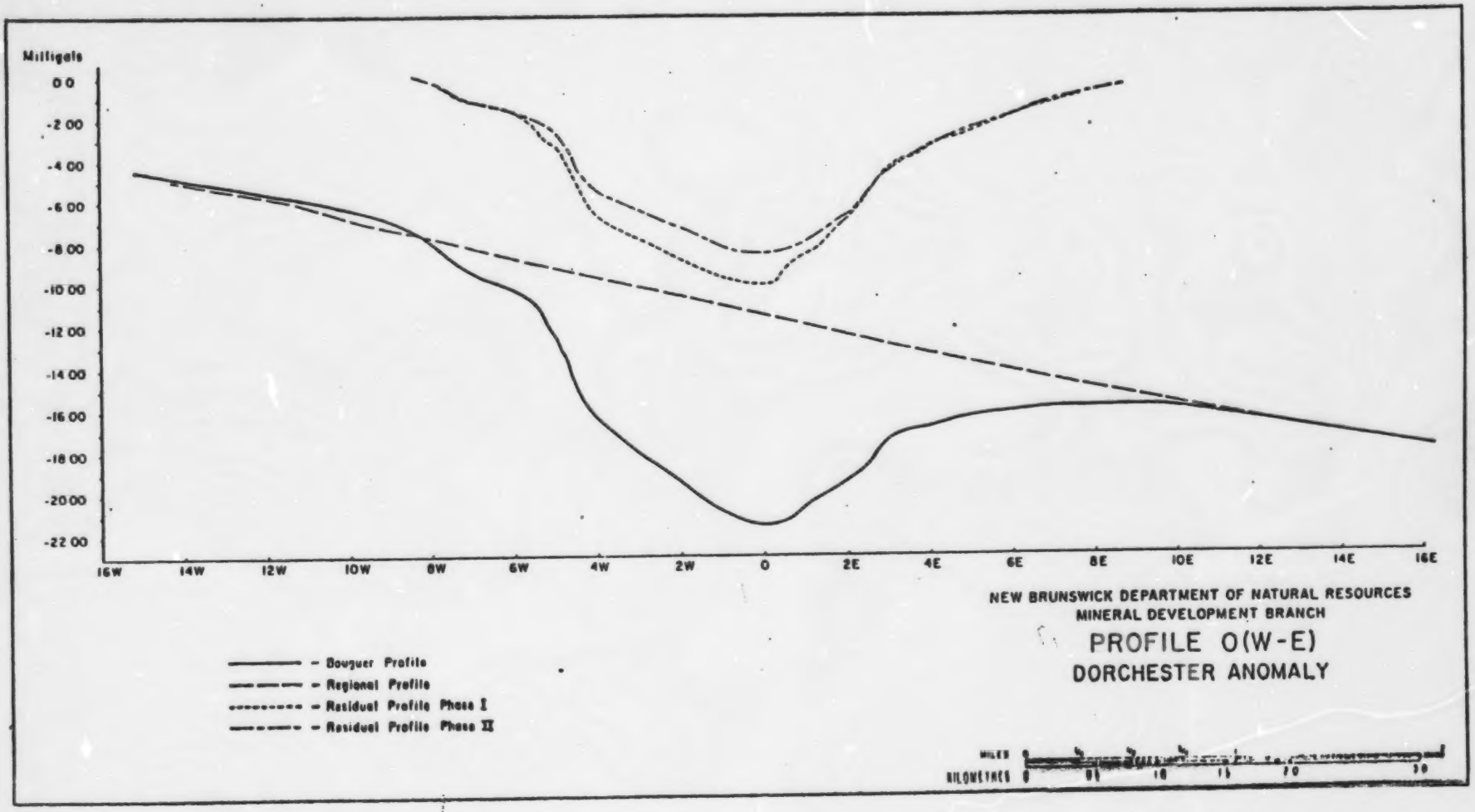

Figure 7. W-E Profile across the Dorchester Gravity Anomaly.

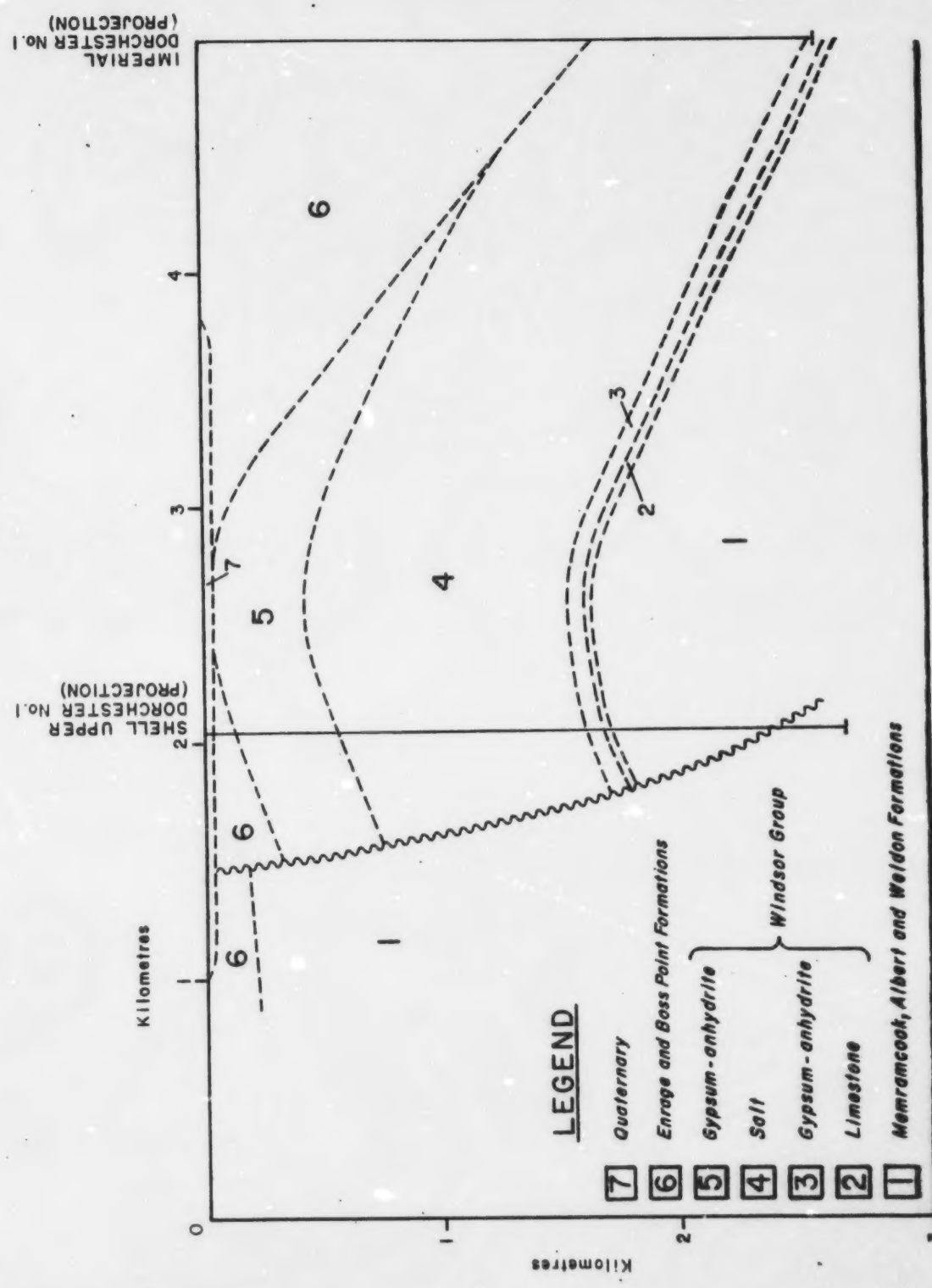

Figure 8. West-East Geological Section of the Dorchester Area.

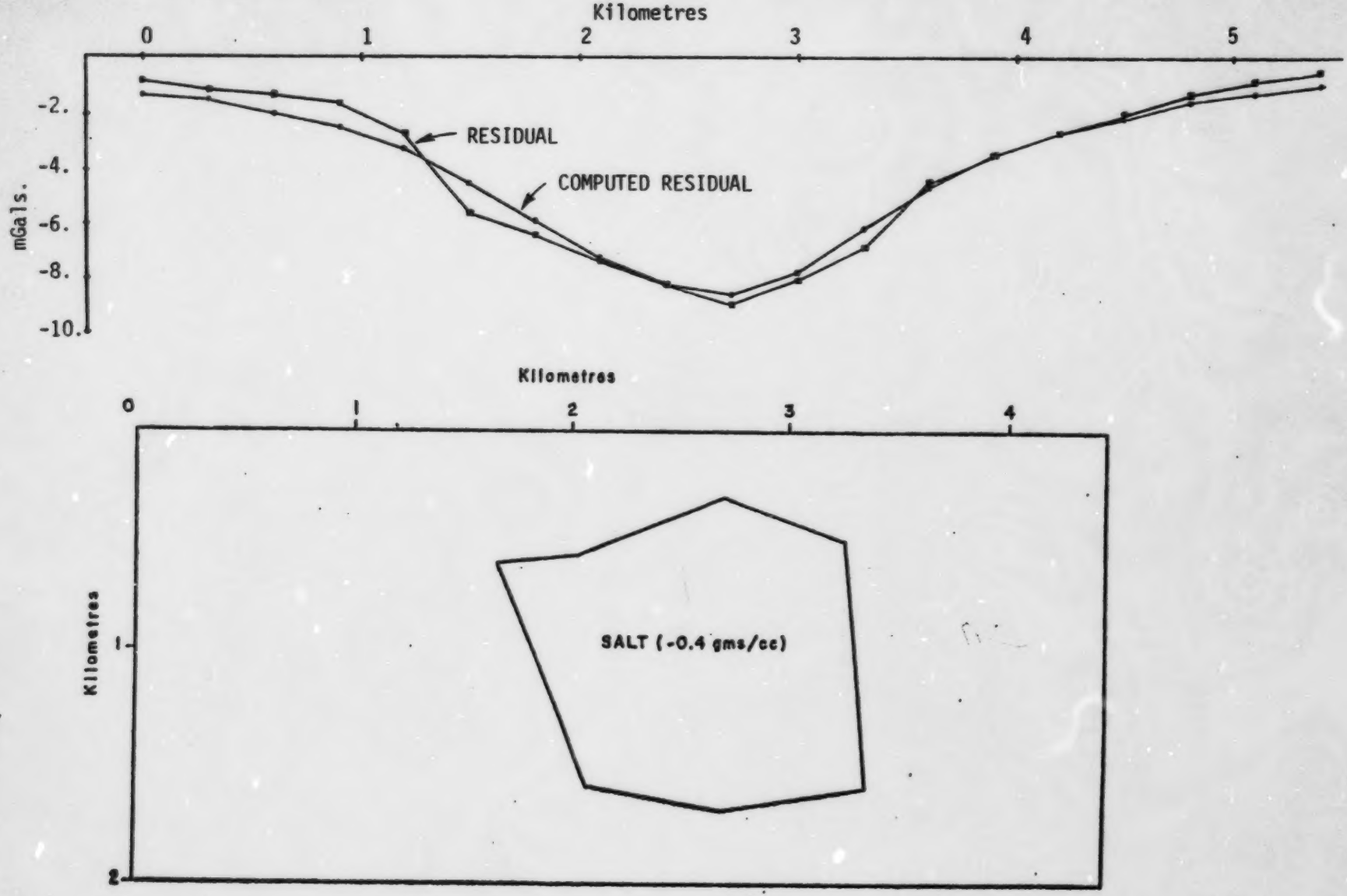

Figure 9. Model of Modified West-East Geological Section of Dorchester Area, Assuming only Salt has Density Contrast

at longitude 65°47'00", latitude 45°29'00"; longitude 65°42'00", latitude 45°31'30" and longitude 65°36'30", latitude 45°34'30" respectively. They are identified in Plate Nos. 82-179Aand 82-179B by the letters A, B and C with minimals of 4 mgal and -.73 mgal respectively.

These anomalies occur in the Marchbank synclinal structure which is bounded on the northwest by the Clover Hill Fault and which onlaps Precambrian volcanics of the Coldbrook Group to the southeast. The syncline contains Carboniferous sedimentary rocks as indicated by geophysics and drilling with a maximum thickness of 6000 feet (Anderle et al., 1979). Gravity modelling of the syncline indicates a maximum depth of approximately 1.6 km.

Stratigraphy in the area of the three anomalies is assumed to be similar and common density values have been used in the modelling of the residual lows. Samples collected from the vicinity of the anomalies for the purpose of density measurements are indicated in Tables 2 to 7.

The three anomalies occur in very rough terrain. This is especially true of the Smithtown anomaly which lies in a river valley flanked by steep hills. Hammer seismic refraction profiles across the floor of the valley at Smithtown indicate shallow bedrock.

In order to assist in the proper evaluation of the gravity data in the area, terrain corrections were applied to the Bouguer Map of Plate Nos. 179A and 179B . However, because of the complexity of the terrain corrections, only portions of interest were corrected. The resulting terrain corrected Bouguer map is

shown in Plate No. 82-180. One profile across each anomaly was modelled using the 2-Dimensional Gravity modelling program. Profiles are located as shown in Plate Nos. 82-179A and 82-179B.

Present gravity coverage and geologic mapping in the Smithtown and Salina areas are inadequate for any thorough gravity modelling. However, the modelled cross section of each anomaly demonstrates a feasible stratigraphic model that would explain the presence of salt.

Computed gravity models for the three areas are shown in Plate Nos. 82-181, 82-182 and 82-183. The models are self explanatory, however, it must be pointed out that each section is based on available geologic and geophysical data and that various other combinations of input data map produce similar computed residual curves.

The salt forms an elongate body which is lensoid in cross section. The length of the salt mass itself is not as yet determined, however, geophysical evidence suggest that it extends from Smithtown to Poodiac, a distance of approximately 25 km. The three gravity anomalies over the Marchbank Syncline reflect bulging of the salt in the vicinity of Smithtown, Salina and Cassidy Lake. Although the dynamics of salt flow in the region is not clearly understood, the location of the salt bulges next to granitic masses may indicate some thermal effect. The transfer of heat from the granite to the salt mass, where the granite only acted as a heat conductor, may have enhanced salt flow. The writers do not see heat transfer as the primary mechanism for salt flow generation but suggest that it may have

been influential.

Millstream Anomaly

The Millstream gravity anomaly is centred at longitude 65°38'00" and latitude 45°42'30", in the southwest portion of the Moncton Basin. It occurs in the Case Syncline, described by Gussow (1953) as a broad synclinal area of Hopewell sediments rimmed by Windsor strata. The south flank of the syncline onlaps pre-Carboniferous rocks and in places is truncated by the Peekaboo, Petitcodiac fault. The Windsor strata in the northwest flank of the syncline rests on Moncton sediments.

The Millstream anomaly was drilled in 1973 (D.H. Millstream No. 1) by the Department of Natural Resources. The top of the Windsor evaporite sequence, consisting of potash bearing salt was intersected at a depth of 925 metres. The hole bottomed at 938 metres but because of technical problems no core was recovered from the last 13 metres.

The stratigraphic section used in the modelling of the Millstream anomaly (Plate No. 82-41) was compiled from data taken from Geological Map No. 845A Sussex (Alcock and MacKenzie, 1942) and from published and internal reports of the Geological Surveys Branch. The computed gravity model of the salt mass is interpreted to be at a depth of 800 metres with a maximum thickness of 200 metres. It is lensoid in shape and from the shape of the gravity anomaly (Plate No. 82-183) pinching out is suggested along strike both to the southwest and northeast.

Plumweseep, Penobsquis, Five Points, Anagance and Portage Vale Anomalies

The Plumweseep (latitude 45°44'30"; longitude 65°27'00"), Penobsquis (latitude 45°46'30"; longitude 65°22'30"), Five Points (latitude 45°49'00"; longitude 65°17'00") Anagance (latitude 45°53'30"; longitude 65°15'00") and Portage Vale (latitude 45°50'30"; longitude 65°13'30") gravity anomalies are located as shown in Figure 10. They occur in the Dunsinane Synclinorium near the western extremity of the Moncton Basin. Except for the Anagance anomaly and part of the Portage Vale anomaly, all the others are coincident with the Anagance Axis, which is a major northeast-trending anticlinal structure running from Plumweseep to Portage Vale.

Computed models for the several anomalies are shown in Plate Nos. 82-184 to 82-187. The salt masses are interpreted to be diapiric, however, gravity data suggest that the diapirs are linked along strike by thinning out in the intermediate areas.

In the Portage Vale model (Plate No. 82-187) two distinct salt diapirs are interpreted. The most southeasterly of the two masses is larger and is coincident with the Anagance Axis. The smaller mass is isolated as a separate diapir. The formation of two distinct diapirs suggest bifurcating of the Windsor Basin in this region either by faulting or by the presence of an intervening basement high resulting in two separate minor basins.

Upper Point de Bute Anomaly

The Upper Point de Bute anomaly is located at longitude 64°14'30" and latitude 45°55'30", 9 km north of Amherst. There are, however,

two other distinct gravity lows in the immediate area. The first, the Aulac Station anomaly (latitude 45°53'00"; longitude 64°18'30"), is located at the mouth of the Aulac River and the second, the Aulac anomaly (latitude 45°51'30"; longitude 64°18'00"), is located 1.5 km southwest of Aulac (Plate No. 82-47). All three anomalies have their long axes oriented in a northeasterly direction.

The Upper Point de Bute and Aulac Station gravity anomalies are coincident with magnetic lows as indicated on Amherst Aeromagnetic Map No. 797 G (GSC, 1960).

Because of the lack of adequate geological control, only the Point de Bute has been modelled. Geology in the area of the three anomalies is poorly understood because of the lack of outcrop due to extensive cover of unconsolidated material.

The computed gravity model for the Point de Bute anomaly is subject to gross errors. Depths and thicknesses of the cover rocks are questionable because of the lack of stratigraphic control. The stratigraphic section (Plate No. 82-188) used in the modelling process, was constructed from a study of data available (Gussow, 1953; van de Poll, 1972). The location of the fault through the section was taken from Spector, 1980. This fault location is more logical in terms of explaining the gravity anomalies at Upper Point de Bute and at Aulac.

The computed model for the Upper Point de Bute gravity anomaly indicates that the salt mass is diapiric with its top at 150 metres depth and bottoming at 1.4 km. If a similar stratigraphy is assumed for the Aulac anomaly, the salt mass

therefore will be of similar shape and probably of comparable depth. The Aulac Station anomaly, however, would then appear to be north of the fault in the upthrust block. In order to compute models for the Aulac and Aulac Station anomalies, it would be necessary to have a better understanding of the local geology.

CONCLUSION

Even though there is a large number of gravity stations in southern New Brunswick, and in particular the Moncton Basin, the distribution can be classed as inadequate to thoroughly assess the true salt-potash potential of the region.

In the Central Carboniferous Basin, data distribution is approximately 6-7 km^2/point. In this case, only regional patterns can be determined with any certainty. However, large target zones have been identified as worthy of further evaluation. These target zones are marked by large northeasterly striking "graben-like" residual gravity lows.

The anomalies modelled in this study, fall within the Moncton Basin. These anomalies are reasonably defined to allow preliminary modelling. In most cases, however, additional gravity coverage is required to compute three dimensional models. The results of the modelling provide reasonable interpretations of the salt masses. The base of the Windsor from Plumweseep to Portage Vale indicate a slope of 5° to the northeast. It is reasonable to assume that this paleoslope continues as far as Middlesex where a ill-defined gravity anomaly exists.

In the Central Carboniferous Basin, large potential zones have been delineated. The data density in this region does not lend to detail analysis. It is recommended that as a first step a gravity survey be conducted in this region to provide a data base of density 4 km^2/point. After this coverage has been achieved, targets can be selected for detailed coverage with a data spacing of 1 point every .5 x .5 km.

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APPENDIX I

INSTRUMENTATION

The following instruments were used by the Department of Natural Resources in the gathering of gravity data during the period 1977-1981:

(1) Gravity Meter (CG-2 Model by SCINTREX)

(2) Distance Measuring Equipment (Model 3810 A by Hewlett Packard)

(3) Aneroid Barometers (American Paulin System)

(4) Zeiss Ni 22 Level

Only brief descriptions of the instruments and their functions are provided here. For more details, the reader is referred to the respective manuals published by the manufacturers.

1. Gravity Meter

The gravity meter used on the project was a Model CG-2 manufactured by SCINTREX LTD. of Toronto. The CG-2 gravity meter is a sensitive balance which measures the attraction of the earth on a small mass within the instrument. This small mass is suspended by springs with all components constructed of fused quartz and very light in weight. A temperature compensating mechanism is built into the meter to correct for expansion and contraction effects due to changes in temperature over the working day. The meter is of the unstable type with the force of gravity maintained in equilibrium by the variable upward restoring force exerted by the meter's spring mechanism.

The actual magnitude of the acceleration of gravity is not measured directly by the meter but only the difference in

acceleration between measuring points. To obtain the actual acceleration, the readings are referenced to control points where the acceleration have been precisely measured. These control points are a network of Gravity Control stations set up throughout New Brunswick and Canada by the Earth Physics Branch (E.M.R.). The gravity meter measures in units of milligals (unit of acceleration). One milligal is 1/1000 cm per second and is equivalent to approximately 1/1,000,000 of the average attraction of the earth at sea level at the equator. The CG-2 meter can be read to 0.005 milligals and has a repeat accuracy of about 0.01 milligals under field survey conditions.

2. Electronic Distance Measuring Equipment (Model HP 3810 A, Hewlett Packard)

The Hewlett Packard 3810-A Total Station is an infra-red distance measuring instrument employing a Gallium Arsenide diode with amplitude modulation. It incorporates a small internal computer and displays horizontal distances corrected for curvature of the earth and atmospheric index of refraction. In addition to horizontal distance, the HP 3810 A display system permits the display of slope distance, vertical distance and zenith angle. The HP 3810 A's display communicates the status of the instrument as well as the quality of the measurement to the operator. Through a variety of displays, the operator can easily tell the operating status of the instrument. Also, the results of an internal statistical analysis on the quality of the measurement displayed is communicated to the operator by three types of display behavior. The three situations communicated are: normal

measurement, marginal measurement, and unable to measure. In addition, the display has indicator lights that tell the operator when the reflector is acquired, when the signal strength is too strong and when the battery is discharged.

Surveying with 3810 A is only feasible when it could be transported to the instrument set up point by vehicle. Its weight (13 kg) and awkwardness made it impractical to carry manually over any distance. The set up time is also quite lengthy and long sight distances are needed to take advantage of its capabilities.

3. Aneroid Barometer (American Paulin System)

Barometric levelling is based on the well known relationship which exists between atmospheric pressure and the height above sea level. It is assumed that within a limited area, the pressures of the particular layers of the atmosphere are the same at the same altitude, if air remains motionless.

The atmospheric pressure is equal to the weight of a vertical column of air extending up to the outer limits of the atmosphere. Thus, if P is the atmospheric pressure at elevation H, then, when the elevation increases by dH, the pressure becomes P-dP. The drop in the pressure is caused by the decrease in the weight of the column of air which has a volume equal to 1 x dH. Therefore, $-dP = 1 \times dH \times P_1$ where P_1 is the unit pressure. Now $dP = 1 \times P_1 \times dH$.

The atmospheric pressure does not depend on the altitude only. Additional controlling factors are atmospheric disturbances, temperature and density of the air mass.

The Paulin Precision Altimeter used during the 1981 field season consists of an evacuated chamber with the sides forced apart by a spring. The compression of this chamber by the atmospheric pressure is magnified and indicated by a system of levers. The instrument uses the "zero-gauging" method of weighing atmospheric pressure. The change in pressure is read directly on the graduated scale by means of a pointer which is operated by a control knob. This altimeter compensates automatically for temperature changes within the instrument. This compensation is realized through the choice of suitable materials and design.

Four precision altimeters were used in this project, all of which were of the Paulin System. Two of the altimeters were of the older model graduated in feet (smallest division = 1 foot, scale range = -1000 feet to +5000 ft.). The two newer altimeters were graduated in metres (smallest division = 0.5 m, scale range = -100 m to +2500 m). The newer altimeters reacted to changes in pressure much faster than the older altimeters graduated in feet. Therefore, the altimeters graduated in metres were used as roving altimeters while the altimeters graduated in feet remained at the base station.

The advantage of having two altimeters at the base and two roving was the elimination of gross errors by comparing the readings of the two altimeters. This process was made easier by keeping altimeters graduated in the same units together.

In preparation for traversing, all four altimeters were placed close to the selected bench mark. A thermometer was

placed where it could hang free without touching any foreign objects such as fence posts or the ground and where air circulation was not impeded. Care was taken to ensure that altimeters and thermometers were out of direct sunlight. It was found that it took between 10 and 15 minutes for the altimeters to fully adjust to conditions at the base station. All altimeters were then set to the desired elevation with the aid of a magnifying glass and the elevation, time, and temperature were noted in log books. The two altimeters graduated in metres were made to agree within 1 metre and the two graduated in feet were to agree within 3 feet.

The amount of time allowed between readings was agreed upon before the survey was to begin. This time was a function of the terrain conditions in which the survey was to take place.

The use of the altimeters was normally confined to areas not accessible with the conventional levelling devices. However, they were also used where information was required as a check and where levelling was not critical. Where the survey was over good roads and a vehicle was used for transportation, the lapse time between readings at traverse and base stations was five minutes. A lapse time of ten minutes was used on trails and a lapse time of fifteen minutes was used for traverses through rough terrain and dense growth. The stations were placed at 500 m intervals. These were measured using the vehicle odometer or a "topofil" unit. A "topofil" unit consists of a small carrying case containing spools of string and a measuring device. The final reading made by the roving altimeters, for all traverses, was back at the base station.

The greatest distance the roving altimeter was normally allowed from the base station was 4 km. However, there were a few times when longer traverses had to be made because of very poor accessibility. On one occasion, a traverse of 7 km was worked. The closure was within the 3 m allowable error.

4. Zeiss Ni-22 Level

The Zeiss Ni-22 is an automatic optical level which is used in the conventional way. Backsights and foresights were recorded for each set-up not exceeding 100 metres. The levelling was checked for misclosure by looping back to the starting bench-mark or by tying into coordinate monuments found along the level route. Misclosure error was not allowed to exceed 24 mm$\sqrt{k}$ where k is the distance in kilometers.

APPENDIX II

THEORY OF THE GRAVITY METHOD

Gravity methods are based on the relationship that gravitational attraction of subsurface bodies depend directly upon their masses and inversely upon some power of the depth of their occurrence. This basic principle evolves directly from Newton's Gravitational Law:

$$F = \frac{G M_1 M_2}{r^2}$$

where F = attracting force
G = universal gravitational constant
M_1 = mass of body No. 1
M_2 = mass of body No. 2
r^2 = distance between their centre of mass

Therefore, the force of attraction between two bodies depends on their masses and the distances separating them. The magnitude of this attractive force on the earth varies with density of the underlying rock and the latitude of the observation station.

In gravity surveying the acceleration rather than the force of gravity is measured. The acceleration of gravity on the earth is approximately 980 cm/sec^2 or 980 gals (1 gal = 1 cm/sec^2). By measuring the relative acceleration of gravity between each station, variations in the gravity field are detected. This change in acceleration being due to density changes in the causative masses below the surface.

Gravity values obtained in the field are referenced to each other by calculating their value on a selected datum plane - the geoid (see section on New Canadian Gravity Datum). Corrections are applied to take into account the gravity differences

caused by the position and topography at the measured station.

Corrections applied to the observed gravity values are:

1. Drift correction
2. Elevation correction
3. Latitude correction
4. Earth Tide correction
5. Terrain correction

Drift Correction

The "drift" correction is required because of reading drift on the gravity meter due to temperature changes, tidal effects, and spring mechanism creep. Since a base gravity meter was not practical, it is compensated for by reoccupying the starting station within a limiting period (usually one hour) and distributing the closure error between the stations. The closure error is assumed to be linear within the limiting loop time of one hour. On long and difficult cross country traverses where precision altimeters are used to obtain elevations, no limiting loop time is used, however, linear drift corrections were still assumed. The drift errors on such traverses are allowable because of the ± 3 m error incurred in the use of the altimeters.

Elevation Correction

Elevation correction takes care of two effects: (1) the free-air effect and (2) the Bouguer effect. The vertical decrease of gravity with increase of elevation is taken care of by the free-air correction. This correction compensates for the difference in elevation between the observation point (station) and the datum surface (usually sea level). The

gravity difference between these two points

$$= \frac{2g_o hR + g_o h^2}{(R + h)^2} = \frac{2g_o h}{R}$$

where g_o = gravity value at sea level
R = radius of the earth
h = elevation of station with respect to sea level

This variation has a magnitude of 0.3086 mgal/m. Since a station at a relatively higher elevation has a lower gravity (because it is further from the centre of the earth), the correction must be added to stations at a higher elevation and must be subtracted from stations at a lower elevation than the reference level.

The Bouguer correction adjusts for the attraction of the rock between the observed station and the datum surface. The gravity difference

$$= 2\pi\sigma h$$

where σ = density of the material (taken as 2.67 gm/c^3 for all data reported in this project)

This variation has a magnitude of

$$0.04193\ \sigma h \quad \text{mgal/m}$$

or .11195 mgal/m

For stations of elevations above the datum, the correction is negative. For stations below the datum, the correction is positive.

Since the free-air and Bouguer corrections are simple constants multiplied by the elevation, they are usually combined into a single "elevation correction factor" Ec.

$$Ec = 0.3086 - 0.04193\ \sigma$$
$$= 0.3086 - 0.04193\ (2.67)$$
$$= 0.19665 \text{ mgal/m}$$

For stations above the datum, Ec is positive and for those below datum, it is negative.

Latitude Correction

The latitude correction adjusts for the gravity increase between the equator and the poles. This increase is caused by the earth's rotation and the difference in the radius at the equator and the poles. Latitude corrections are based on gravity differences derived directly from the gravity formula for theoretical gravity G_T calculated on the 1967 Geodetic Reference System (see New Canadian Gravity Datum).

$$G_T = 978031.85\ (1.0 + 0.005278895\ \sin^2\theta + 0.000023462\ \sin^4\theta)$$

This value is subtracted from the observed field value of gravity.

Earth Tide Correction

The earth tide correction compensates for the change in gravity caused by the attraction of the sun and moon. This correction varies cyclically during the day and is similar to the tidal effect in the oceans. However, it cannot be determined by tidal theory. It can be determined by the monitoring of a base gravity meter in the survey area. It was not economical to have a base gravity meter and therefore correction of earth tide effects were assumed to be accounted for in the "drift correction".

Terrain Correction

The plane of calculation of gravity data is often arbitrarily selected at sea level. In regions of rough terrain, negative effects were produced by valleys below and hills above the elevation plane of the station. Hills have an upward attraction causing the computed value to be too small. Valleys are ignored in the Bouguer calculation which also cause the reduced value to be too small. Thus, terrain correction for both these effects is always positive. The magnitude of this effect is proportional to the density of the rock.

Terrain corrections involve very tedious calculations. To make the correction, a topographic map of the area is divided into zones and radial compartments. The effect of each compartment on the observed value is calculated. The sum of the effects is then added to the gravity value at the station under investigation.

Since the process is very time consuming, terrain corrections are normally only applied to areas of steep topography and in particular, over gravity anomalies of interest.

Terrain corrections were, therefore, not calculated for the bulk of the data gathered on this project except for gravity anomalies in the Smithtown, Salina and Salt Springs area. For the published magnetic tape of gravity data and the 1:50,000 gravity maps, terrain corrections were not made.

For the calculation of terrain effects in the Smithtown, Salina, and Salt Springs area, the writers used the following technique. Twenty 1:10,000 contoured topographic orthophoto maps of the Smithtown,Salina,Salt Springs and surrounding area were

photographically reduced to 1:20,000 scale and manually digitized with a graticule spacing of 500 m.

Using the terrain correction computer program of Nagy (1966), terrain effects from masses within a 10 km radius were calculated for each grid point. Cross checking the computer calculations with the use of Bible Charts (Bible, 1962), showed that Nagy's computations were not accurate for a region within a radius of 1.5 km of the station. The two methods were, therefore, combined where Bible's charts were used for the inner zone, within a radius of 1.5 km of each station (Bible's zones D, E, F, and G) and Nagy's computations were used for the region 1.5-10 km. The two values were summed and this correction applied to the observed values.

Bouguer Anomaly

Final reduction of the gravity data resulted in the compilation of Bouguer Anomaly values:

$$G_B = G_o - G_T \pm E_c + T_c$$

where G_B = Bouguer anomaly

G_o = Observed gravity (adjusted for drift and closure)

G_T = Theoretical gravity

E_c = Elevation correction

T_c = Terrain correction (applied only in special cases)

All Bouguer Anomaly data reported in this project have been compiled with sea level as the reference plane and rock density of 2.67 gm/cm^3.

APPENDIX III

D.N.R. PLATE No.	COMPUTER MAP CODE	N.T.S. MAP NO./NAME		GRAVITY STATIONS TOTAL	GRAVITY STATIONS PLOTTED
82-I3	435	11D/13	UNIACKE	30	29
-05	436	11D/12	HALIFAX	53	46
-06	443	21A/9	CHESTER	36	36
-I4	444	21A/16	WINDSOR	40	39
-I5	445	21A/15	GASPEREAU LAKE	36	36
-07	446	21A/10	NEW GERMANY	37	36
-08	453	21A/11	MILFORD	31	31
-I6	454	21A/14	BRIDGETOWN	38	36
-I7	455	21A/13	GRANVILLE	11	10
-09	456	21A/12	DIGBY	41	38
-I0	463	21B/9	CENTREVILLE	178	178
-I8	464	21B/16		193	192
-I9	465	21B/15	CAMPOBELLO	70	70
-II	466	21B/10	GRAND MANAN	53	53
-I2	473	21B/11		14	14
-20	474	21B/14	FAIRHAVEN	1	1
-46	535	11E/13	PUGWASH	23	23
-37	536	11E/12	OXFORD	30	30
-29	537	11E/5	BASS RIVER	33	31
-2I	538	11E/4	KENNETCOOK	35	35
-22	54I	21H/1	WOLFVILLE	33	33
-30	542	21H/8	PARRSBORO/ FIVE ISLANDS	22	22

D.N.R. PLATE No.	COMPUTER MAP CODE	N.T.S. MAP NO./NAME		GRAVITY STATIONS TOTAL	GRAVITY STATIONS PLOTTED
82-38	543	21H/9	RIVER HEBERT/ SPRINGHILL	102	52
-47	544	21H/16	AMHERST	961	285
-48	545	21H/15	HILLSBOROUGH	905	430
-39	546	21H/10	ALMA	493	190
-3I	547	21H/7	CAPE CHIGNECTO	24	24
-23	548	21H/2	BERWICK	28	27
-24	55I	21H/3	MARGARETVILLE	4	4
-32	552	21H/6	SALMON RIVER	14	11
-40	553	21H/11	WATERFORD	661	258
-49	554	21H/14	PETITCODIAC	2840	1025
-50	555	21H/13	CODYS	650	306
-4I	556	21H/12	SUSSEX	2772	913
-33	557	21H/5	LOCH LOMOND	574	346
-25	558	21H/4	MISPEC	53	50
-26	56I	21G/1	MUSQUASH	123	122
-34	562	21G/8	SAINT JOHN	176	153
-42	563	21G/9	HAMPSTEAD	200	163
-5I	564	21G/16	GRAND LAKE	375	196
-52	565	21G/15	FREDERICTON	534	299
-43	566	21G/10	FREDERICTON JTN.	337	182
-35	567	21G/7	McDOUGALL LAKE	35	35
-27	568	21G/2	ST. GEORGE	77	74
-28	57I	21G/3	ST. STEPHEN	108	86

D.N.R. PLATE No.	COMPUTER MAP CODE	N.T.S.	MAP NO./NAME	GRAVITY STATIONS TOTAL	GRAVITY STATIONS PLOTTED
82-36	572	21G/6	ROLLING DAM	187	152
-44	573	21G/11	McADAM	130	99
-53	574	21G/14	CANTERBURY	346	171
-54	575	21G/13	FOSTERVILLE	79	69
-45	576	21G/12	FOREST CITY	11	11
-82	635	11L/13		5	5
-73	636	11L/12	MALPEQUE	8	8
-64	637	11L/5	SUMMERSIDE	10	9
-55	638	11L/4	CAPE TORMENTINE	71	55
-56	64I	21I/1	PORT ELGIN	528	324
-65	642	21I/8	CAPE EGMONT	6	6
-74	643	21I/9	O'LEARY	10	10
-83	644	21I/16	TIGNISH	9	8
-84	645	21I/15	PORT SAPIN	24	24
-75	646	21I/10	RICHIBUCTO	173	135
-66	647	21I/7	BUCTOUCHE	232	178
-57	648	21I/2	MONCTON	877	520
-58	65I	21I/3	SALISBURY	736	415
-67	652	21I/6	HARCOURT	609	150
-76	653	21I/11	ROGERSVILLE	575	159
-85	654	21I/14	KOUCHIBOUGUAC	368	115

D.N.R. PLATE No.	COMPUTER MAP CODE	N.T.S. MAP NO./NAME		GRAVITY STATIONS TOTAL	GRAVITY STATIONS PLOTTED
82-86	655	21I/13	NEWCASTLE	330	121
-77	656	21I/12	BLACKVILLE	88	83
-68	657	21I/5	SALMON RIVER ROAD	44	44
-59	658	21I/4	CHIPMAN	110	80
-60	66I	21J/1	MINTO	53	52
-69	662	21J/8	BOIESTOWN	45	44
-78	663	21J/9	DOAKTOWN	49	47
-87	664	21J/16	McKENDRICK LAKE	37	37
-88	665	21J/15	TUADOOK LAKE	31	31
-79	666	21J/10	HAYESVILLE	26	26
-70	667	21J/7	NAPADOGAN	61	59
-6I	668	21J/2	BURTTS CORNER	112	79
-62	67I	21J/3	MILLVILLE	132	108
-7I	672	21J/6	COLDSTREAM	68	68
-80	673	21J/11	JUNIPER	47	47
-89	674	21J/14	PLASTER ROCK	95	72
-90	675	21J/13	AROOSTOOK	67	67
-8I	676	21J/12	ANDOVER	68	68
-72	677	21J/5	FLORENCEVILLE	104	97
-63	678	21J/4	WOODSTOCK	185	158
-I25	735	11M/13		6	6
-II3	736	11M/12		5	5

APPENDIX IV

Column Number	Description	Fortran Format
1-2	Year of observation	I2
3-4	Source of identification 0 - Earth Physics Branch 1 - Department of Natural Resources 2 - Burke (Plumweseep) 3 - N.S. Research Foundation (Cassidy Lake) 4 - Spector (Plumweseep)	I2
5-11	Station number	I7
12-15	Signed latitude degrees (north positive)	I4
16-21	Decimal minutes of latitude to 0.01 minutes	F6.2
22-25	Signed longitude degrees (east positive)	I4
26-31	Decimal minutes of longitude to 0.01 minutes	F6.2
32-38	Elevation of station above mean sea level (metres)	F7.2
39	Elevation accuracy code 0 Unknown 1 ± 0.01m 2 ± 0.03m 3 ± 0.1m 4 ± 0.3m 5 ± 1.0m 6 ± 3.0m 7 ± 10.0m 8 ± 30.0m 9> ± 30.0m	I1
40-44	Depth of water above or below station (metres)	F5.1
45	Water code 0 - A depth of water or thickness of ice was present at the observation site, but was not measured 1 - Land station 2 - A depth of water for an observation taken on the surface of a lake or the sea (dynamic gravimeter)	I1

Column Number	Description	Fortran Format
	3 - A depth of water for an observation taken on the bottom of a lake or the sea 4 - Thickness of ice for a measurement taken on the surface of an ice cap or glacier 5 - Same as 2 but with a static gravimeter on sea or lake ice	
46-53	Adjusted gravity value (IGSN71 system) in MGal	F8.1
54-59	Bouguer gravity value in MGal	F6.1
60	Marks plotted or repeated stations * plotted R repeat	A1

APPENDIX V

PROCEDURE FOR DENSITY MEASUREMENTS

Most of the density measurements were made in the geophysics laboratory at the University of New Brunswick. The one exception were measurements of the dry density of five core samples from the Millstream and Salt Springs boreholes by Atlantic Analytical Services.

The basic procedure used for density determinations was as follows. Slabs of rock collected from outcrops in the field were broken into hand-size samples (usually in the weight range 200-500 gms) by using a hydraulically operated rock splitter. Core samples of 5-10 cm in length from boreholes have also been used for some of the determinations. All of the samples were dried in an oven at a temperature of 50°C for a minimum period of 48 hours. The weights of the dried samples were then obtained using the top pan of a Mettler P1200 analytical balance. The weight of the sample can be determined in this way to the nearest 0.01 gms, with an estimated error of ± 0.02 gms/cm^3.

After this first weighing, the dry samples were placed under water in a desiccator and a partial vacuum applied with a hand pump. The samples were left for one week in the desiccator to allow full saturation of the pore spaces and fractures by water. The samples were then removed from the desiccator, their surfaces dried with paper towel, and reweighed on the top pan of the Mettler analytical balance.

An elastic band was next placed around a rock sample and was used to suspend the sample from a hook attached to the

bottom of the weighing pan. The suspended sample was then completely immersed in a container of water by raising the container to the level of the sample with a laboratory jack. In this way, the weight of a saturated sample in water was obtained, after applying a small correction for the suspended weight of the elastic band.

For the evaporite samples, and those sedimentary rock samples that contained a significant proportion of water soluble minerals, kerosene was substituted for water as the immersing liquid. In this case, of course, no attempt was made to saturate the samples with water, so that only the dry density could be obtained for this set of samples.

The density values for individual samples immersed in water were obtained from the following equations:

Grain density σg

$$\sigma g = \frac{W_1}{W_1 - W_3}$$

Dry density σd

$$\sigma d = \frac{W_1}{W_2 - W_3}$$

Saturated density σs

$$\sigma s = \frac{W_2}{W_2 - W_3}$$

where W_1 is the weight of the dried sample in air
W_2 is the weight of the saturated sample in air
W_3 is the weight of the saturated sample suspended in water.

(N.B. The assumption is made that the density of the water used is 1.00 gms/cm^3).

For the samples weighed in kerosene, only the dry density could be calculated.

Dry density of σd

$$\sigma d = \frac{K(W_1)}{(W_1-W_2)}$$

where K is the density of the kerosene used
W_1 is the weight of the sample in air
W_2 is the weight of the sample suspended in kerosene

If more than one sample of rock unit was available at a particular location, the mean and standard deviation of the set of samples are listed in the following tables in order to represent the best estimate of density of the rock unit.